



OMPS Limb Profiler

An Integrated Approach to Ozone Monitoring

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Limb Profiler**Limb Development Team**

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Ozone EDR Profile Requirements

**Provide profiles of the volumetric concentration of ozone****Performance requirements:**

Horizontal cell size : 250 km

Vertical cell size : 3 km

Horizontal coverage : global for SZAs < 80 degrees

Vertical coverage : tropopause height (or 8 km)- 60 km

Measurement range : 0.1-15 ppmv

Measurement accuracy :

tropopause - 15 km : greater of 20% and 0.1 ppmv

15 - 60 km : greater of 10% and 0.1 ppmv

Measurement precision :

tropopause height- 15 km : 10%

15 - 50 km : 3%

50 - 60 km : 10%

Long term stability : 2% over 7-year single sensor lifetime

Maximum local average revisit time : 4 days

Exceptions to EDR performance (precision and accuracy)

Ozone volume mixing ratio < 0.3ppmv

Volcanic aerosol loading - CCD saturation - optical depth

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Vertical Cell Size Drives to Limb Geometry and Profiling Drives to UV/Vis/NIR Radiance Measurements



- **SBUV/2 Heritage**
 - 8-12km vertical resolution
 - Sensitivity provides vertical coverage from 30-50 km
- **OMPS Limb Sensor**
 - Vertical cell size threshold of 5 km requires limb-viewing geometry
 - ♦ 3 km vertical cell size with 1 km sampling achieved with current design
 - High-altitude (28-60 km) profiling requirements met with UV ozone band
 - Low-altitude (tropopause height-28 km) profiling requirements met with visible ozone band
 - Aerosol correction requires UV, Vis, and NIR observations
 - Three cross-track samples at 250 km spacing provide maximum local average revisit of 4 days
 - Limb data centered on flight track, co-located with Total Column and Nadir Profile measurements
 - Calibration stability maintained on-orbit by periodic solar observations

**Remote Sensing of Limb-Scattered Solar Radiation Shares
Atmospheric Radiative Transfer Physics, Calibration Techniques with
OMPS Nadir Sensor**

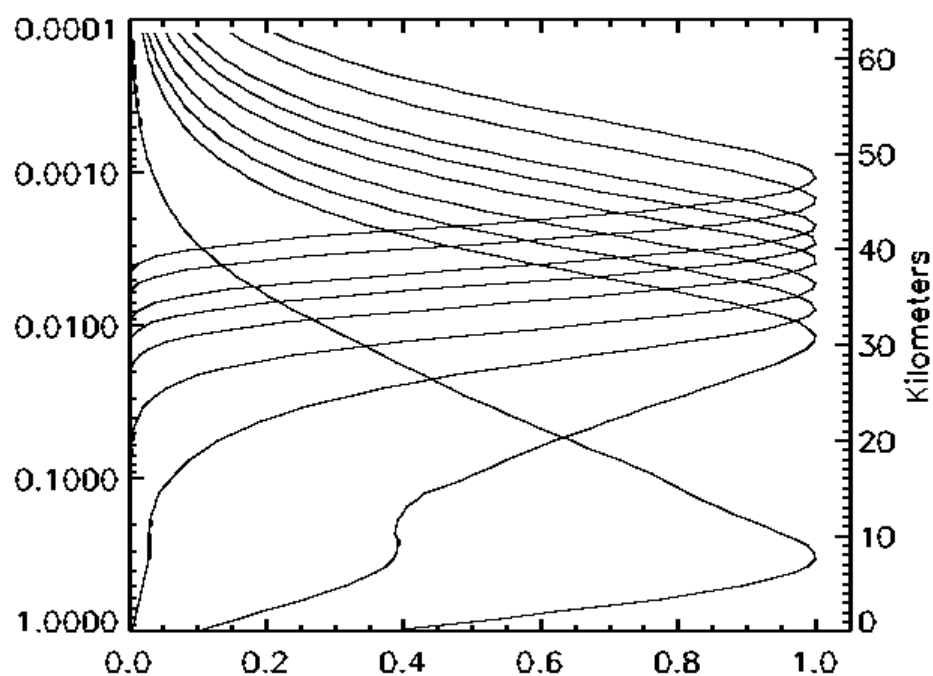


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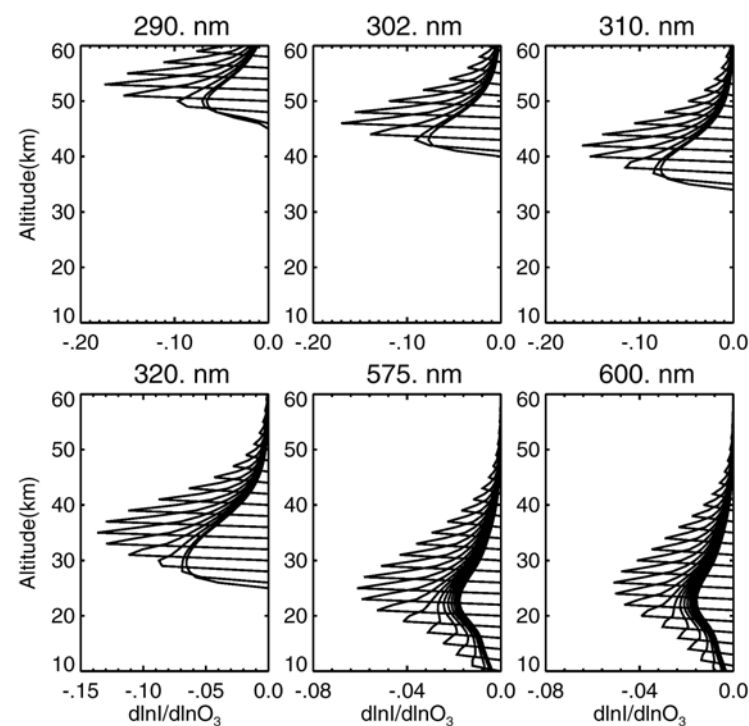
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Comparison of Nadir Profile and Limb Profile
Single Scattering Kernels

Nadir Profile



Limb Profile

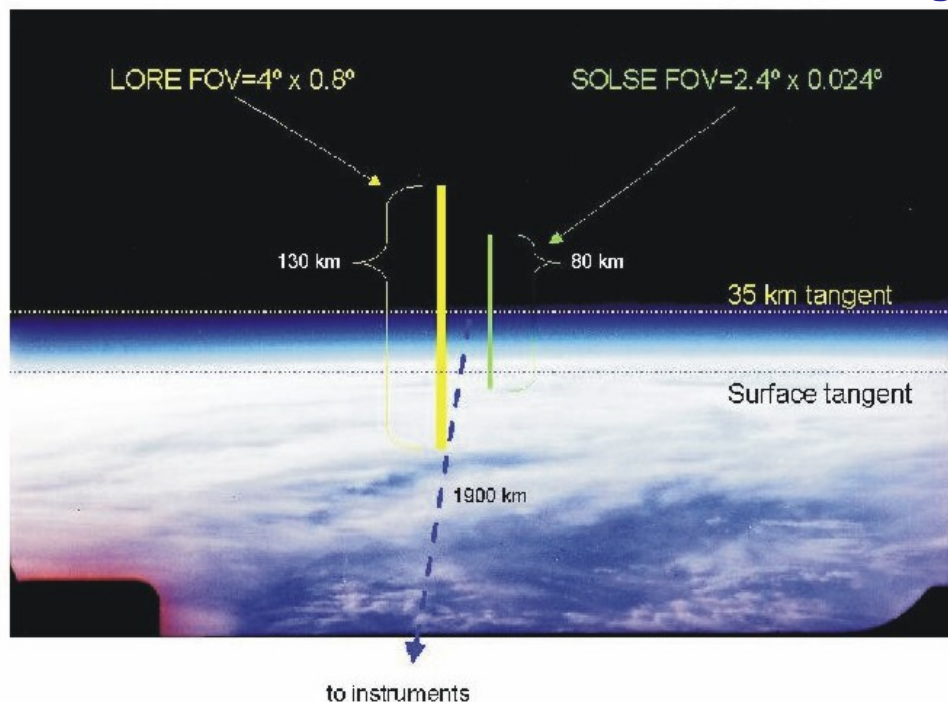


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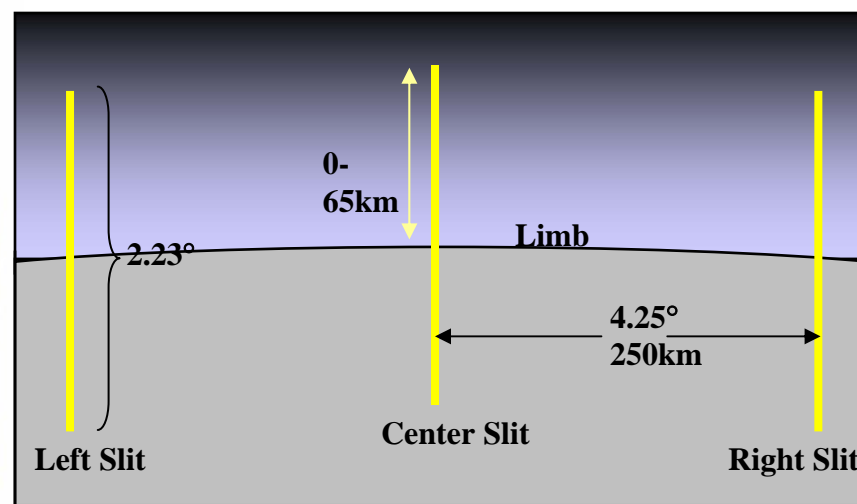
OMPS Limb Sensor Views the Limb Along the Satellite Track



Photo from GSFC's SOLSE/LORE Shuttle flight



OMPS limb sampling



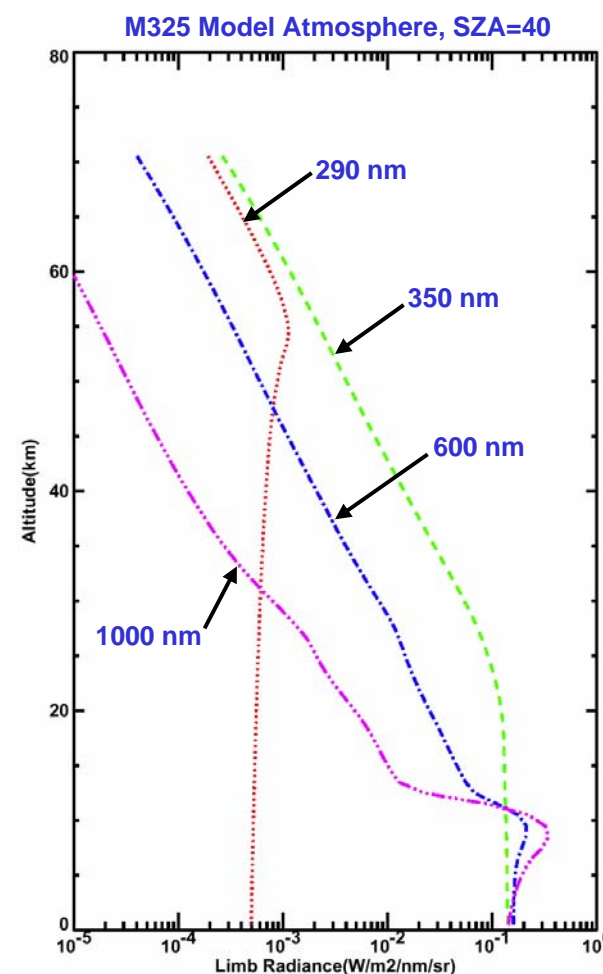
- OMPS limb sensor has 3 slits separated by 4.25 degrees
- 38 second reporting period: 250 km along track
- 130 km (2.23 degree) vertical FOV at limb for 0-60 km coverage plus offsets (pointing, orbital variation, Earth oblateness)

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Sensor is based on a Prism Spectrometer

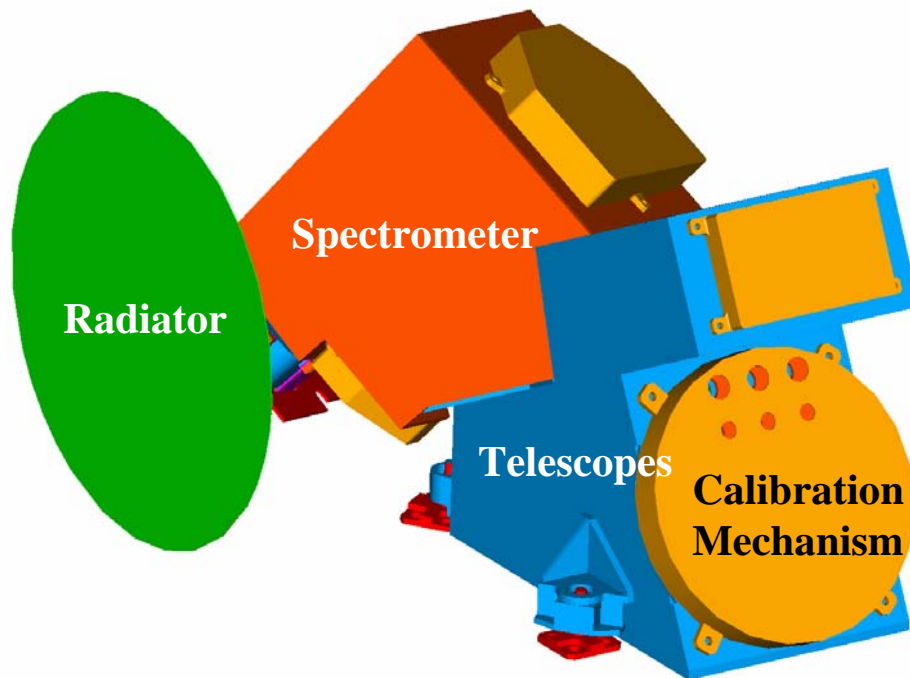


- Prism spectrometer provides spectral coverage from 290 nm to 1000 nm
- Scene dynamic range accommodated with 4 gain levels:
 - Aperture split provides two images/slit along the vertical direction of the focal plane
 - Two integration times for additional discrimination
- Wavelength-dependent resolution of prism spectrometer is consistent with ozone spectral detail over this range
- Three slits provide three cross-track samples with a single spectrometer and no moving parts
- All three slit samples are included on a single focal plane
- Radiances nearly simultaneous in altitude and wavelength
- Limb radiances sampled multiple times within 38 second integration time



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Limb Sensor Design



- Three 2-aperture telescopes
 - Large and small apertures for each slit
 - 4.6x intensity difference between high and low gain images

Single spectrometer/focal plane

- Fused silica prism
- Windowed 740 x 340 CCD at -45°C

Two interleaved integration times

- 1.688 and 0.084 s
- 2 opt gains x 2 integ t = 4 gain levels
- Inter-range gain ratios of 4.6, 4.4, 4.6

Design features:

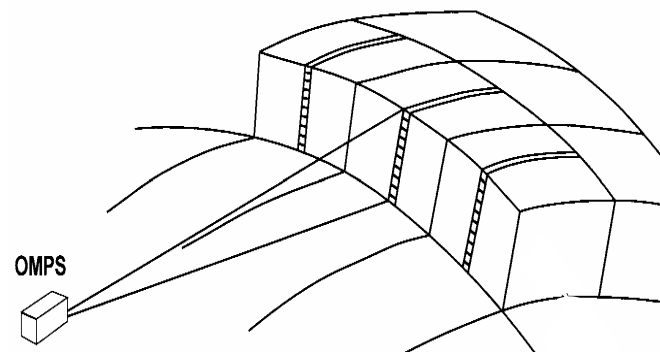
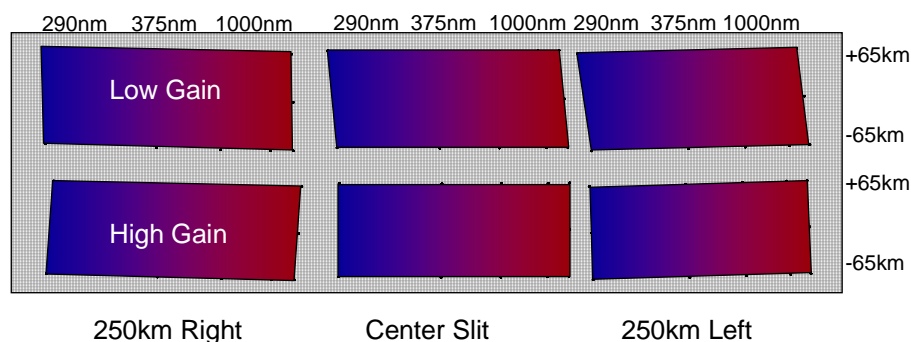
- Mass: 12.5 kg (without electronics)
- Volume: 45 L x 28 H x 30 W (in cm)
- Titanium structure/mounts
- BK7 and fused silica optics
- Transmissive diffusers: working and reference
- Focal plane spectral filtering

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Radiance profiles constructed from 4 gain level images

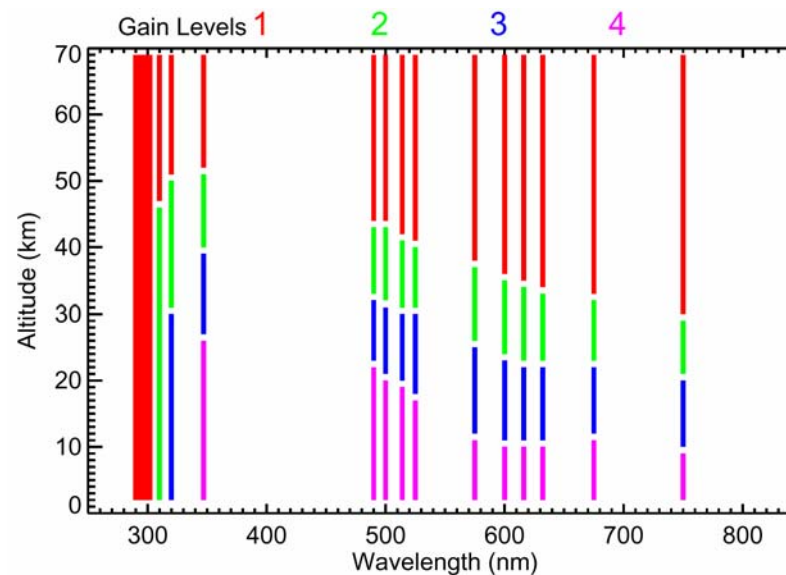
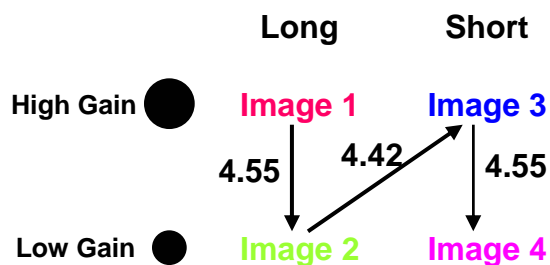


Simultaneous imaging of all three slits



- Focal plane images as viewed from behind CCD
- Spectral and spatial smiles of ~8 pixels
- Inter-image spacing of 50 pixels (vertical) and 20-35 pixels (spectral)

4 gain levels



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Expected SNRs



SNRs allocated
to meet
precision
requirements

End-of-life,
minimum limb
radiance, 38
second report
period

Shaded areas
represent
region with a
SNR allocation.

Minimum SNR for Spec Radiance Conditions

Wavelength nm	Altitude [km]									Ref.
	0 - 15	15 - 28	28 - 38	38 - 43	43 - 45	45 - 47	47 - 50	50 - 53	53 - 60	
290.0	212	235	276	318	346	360	378	417	308	263
293.0	255	283	331	381	415	434	459	481	326	277
296.0	299	331	386	441	482	506	537	541	339	287
299.0	371	409	473	543	601	639	639	541	316	264
302.0	610	662	747	857	852	815	729	602	346	289
310.0	852	916	1,023	1,163	1,116	1,022	857	695	397	332
320.0	1,499	1,509	1,489	1,207	1,082	957	789	639	373	314
350.0	2,383	2,367	1,821	1,514	1,328	1,165	954	775	458	390
352.5	2,383	2,367	1,821	1,531	1,344	1,177	964	783	464	395
400.0	2,369	2,367	2,444	1,808	1,586	1,394	1,144	934	568	487
500.0	2,540	2,540	2,561	1,843	1,847	1,847	1,552	1,280	801	695
525.0	2,540	2,540	2,444	1,837	1,611	1,418	1,167	955	582	498
575.0	2,540	2,540	2,444	1,817	1,593	1,402	1,153	944	575	491
600.0	2,540	2,540	1,811	1,591	1,398	1,228	1,008	823	492	420
675.0	2,540	2,540	1,811	1,298	1,135	992	807	653	377	319
1000.0	2,540	802	312	195	159	130	95	68	31	25
4 gain level system with 2 optical gain levels and 2 integration times										
15 1.688 sec and 30 0.084 sec frames w/opt des 720rev3										

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Limb Profile Ozone Algorithm



- OMPS is adapting the SOLSE / LORE algorithm developed by Drs. Ben Herman and Dave Flittner (U. of Arizona)
- Herman code (*Applied Optics*, v. 34, 1995)
 - Multiple scattering solution in a spherical atmosphere
 - ♦ Molecular and aerosol scattering
 - ♦ Ozone absorption
 - Includes polarization
- Combines spherical multiple scattering solution with integration of source function along line of sight

$$I_{\text{Limb}}^{\text{Total}} = \int_0^{\tau(T)} \omega_0 J e^{-\tau} d\tau$$

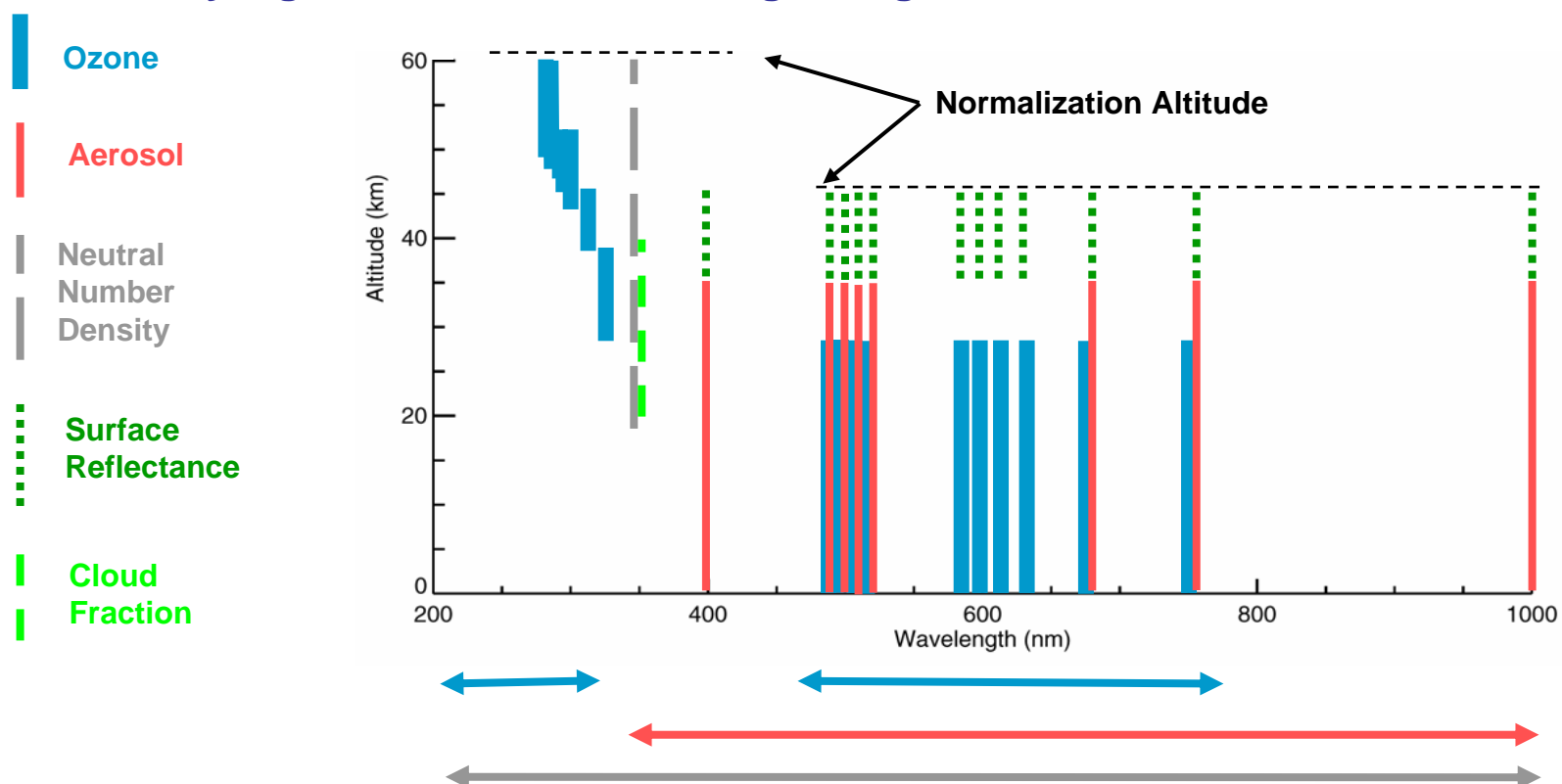
J - source function
 ω_0 - single scatter albedo
 τ - optical depth

- Enhancements by OMPS team include:
 - Additional channels in UV, visible, and near IR
 - Aerosol extinction profile retrievals at non-ozone-absorbing wavelengths
 - Bulk neutral density retrievals
 - Effective surface reflectance and cloud fraction retrievals
- SOLSE/LORE reflight in July 2002 will provide improved data for validation

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OMPS Channels Selected to Optimize
EDR performance

- OMPS utilizes the UV and visible spectrum to measure ozone
 - Middle and near-ultraviolet channels provide coverage from 28 to 60 km
 - Visible channels provide coverage from tropopause to 28 km
- Additional channels between 350 and 1000 nm provide characterization of Rayleigh and aerosol scattering background



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Baseline Channels



- Spectral Coverage, Resolution, and Sampling are Matched to Ozone Absorption Spectrum and Algorithm Requirements

— Ozone Absorbing
— Reference

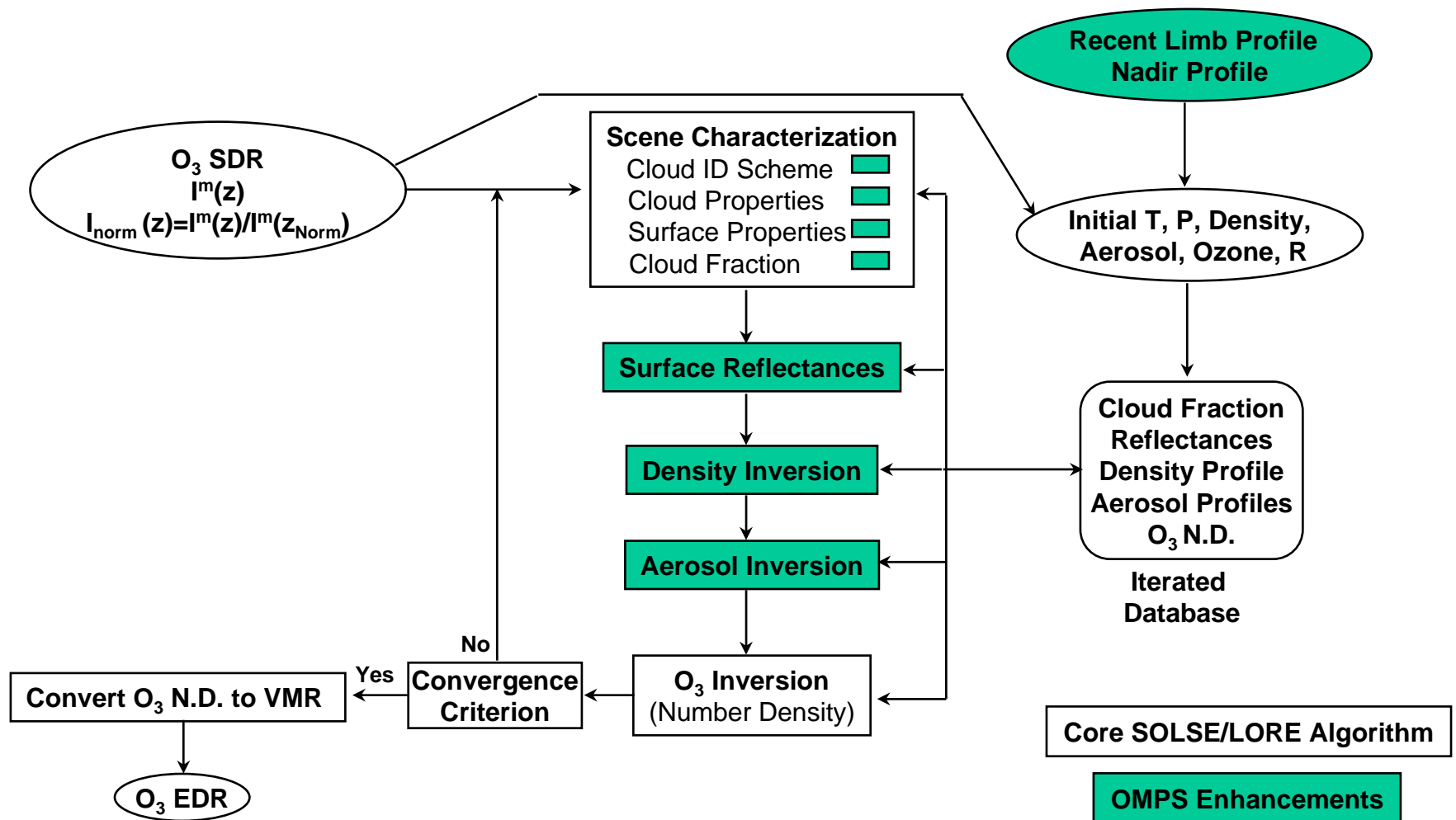
Pairs

Triplets

Channel	Bandwidth	Pixels	Application
290 nm	3 nm	4	Ozone 50-60 km
293 nm	3 nm	4	Ozone 50-60 km increased precision
296 nm	3.5 nm	4	Ozone 47-53 km
299 nm	3.5 nm	4	Ozone 47-53 km increased precision
302 nm	4 nm	4	Ozone 43-53 km
310 nm	4 nm	4	Ozone 38-45 km
320 nm	5 nm	4	Ozone 28-38 km
347 nm	6 nm	4	Reference, neutral number density
353 nm	6 nm	4	Cloud fraction
400 nm	5 nm	2	Aerosol, surface reflectivity
490 nm	9 nm	2	Ozone trop-28 km, aerosol, surface reflectivity
500 nm	9 nm	2	Ozone trop-28 km, aerosol, surface reflectivity
514 nm	10 nm	2	Ozone trop-28 km, aerosol, surface reflectivity
525 nm	11 nm	2	Ozone trop-28 km, aerosol, surface reflectivity
575 nm	14 nm	2	Ozone trop-28 km, aerosol, surface reflectivity
602 nm	16 nm	2	Ozone trop-28 km, aerosol, surface reflectivity
616 nm	16 nm	2	Ozone trop-28 km, aerosol, surface reflectivity
632 nm	16 nm	2	Ozone trop-28 km, aerosol, surface reflectivity
675 nm	21 nm	2	Ozone trop-28 km, aerosol, surface reflectivity
750 nm	24 nm	2	Ozone trop-28 km, aerosol, surface reflectivity
1000 nm	40 nm	2	Aerosol, surface reflectivity

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Baseline EDR Algorithm

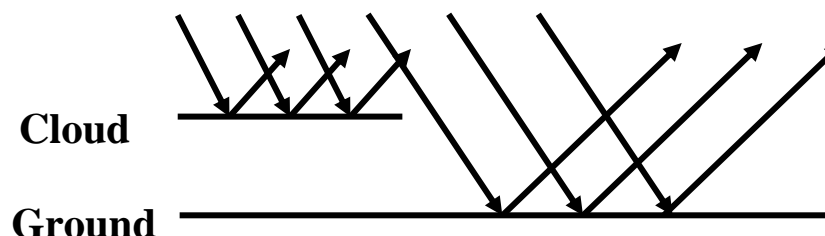


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Scene Characterization



Baseline approach



Radiance multiple scattering component depends on lower boundary conditions

	Terrain		Cloud	
	UV	Visible	UV	Visible
Reflectance	N7 TOMS DB (Herman & Celarier)	Iterated Solution	0.8	0.8
Pressure/ Altitude	CrIS		VIIRS/ OMPS 1000nm channel	

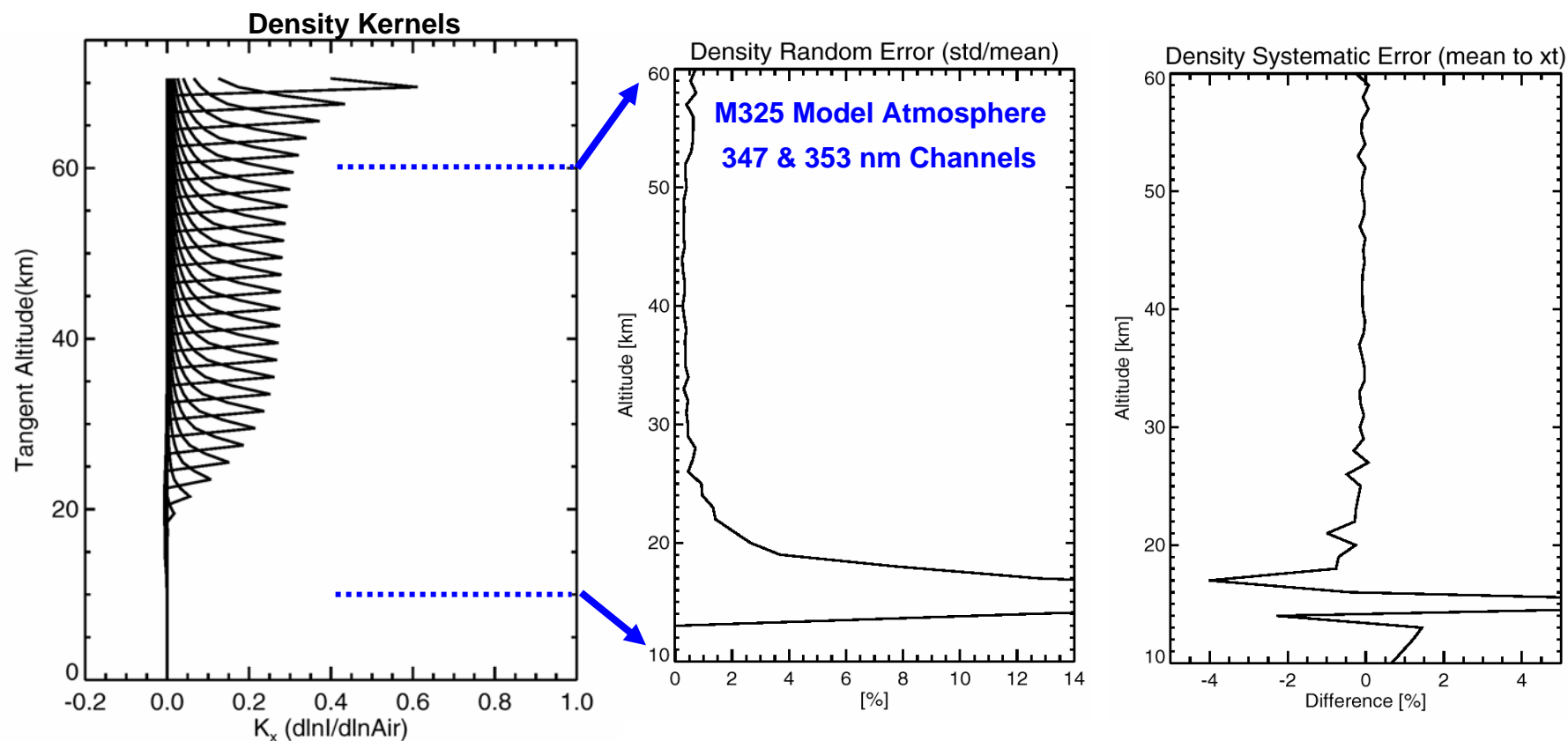
- Spatial variation in cloud and surface reflectivity
- Radiances-weighted average (cloud fraction) of clear sky and cloud
- Iterated solution for cloud fraction from 347, 353 nm channels

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Density Inversion



- Density profile needed for Rayleigh scattering and to convert ozone number density to volume mixing ratio
- Simultaneous ozone and density inversion



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Aerosol Inversion



- Aerosol inversion performance is specified in terms of effect on ozone
- Aerosol knowledge must be sufficient to account for aerosol signal in ozone absorbing channels
- Baseline approach is a 2-step procedure
 - Invert limb radiances in non-ozone absorbing channels for aerosol extinction (optical depth/km)
 - Interpolate/extrapolate aerosol extinction to ozone absorbing channels using Angstrom power law formulation

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Aerosol Kernels

Background (pre-Pinatubo)

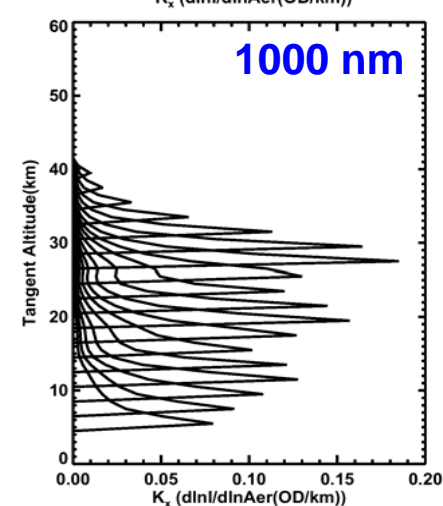
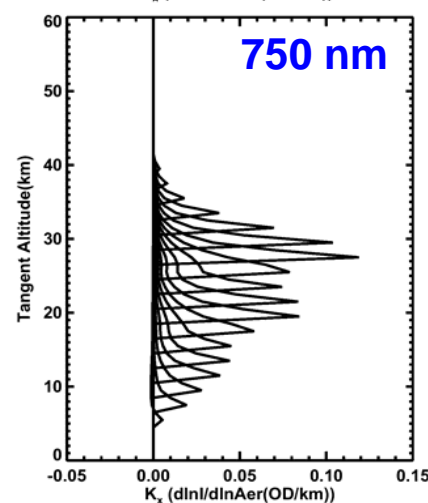
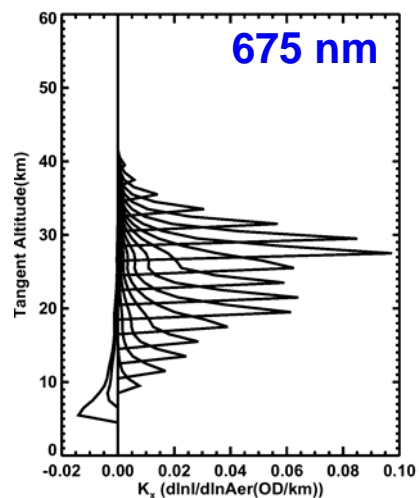
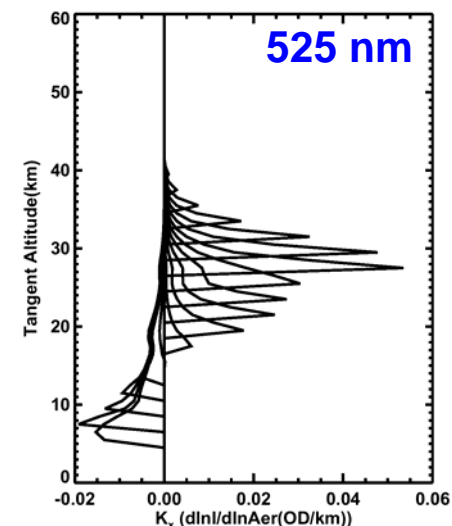
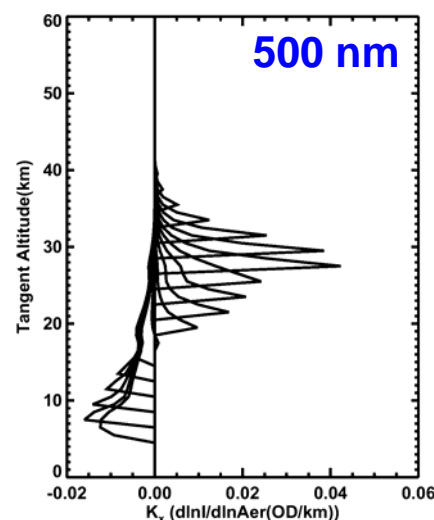
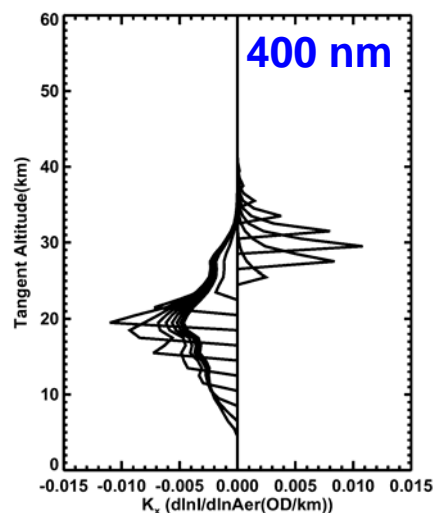


Sharply peaked kernels

Optically thin region-positive kernels

Optically thick region-negative kernels

Insensitive to aerosol at transition altitudes



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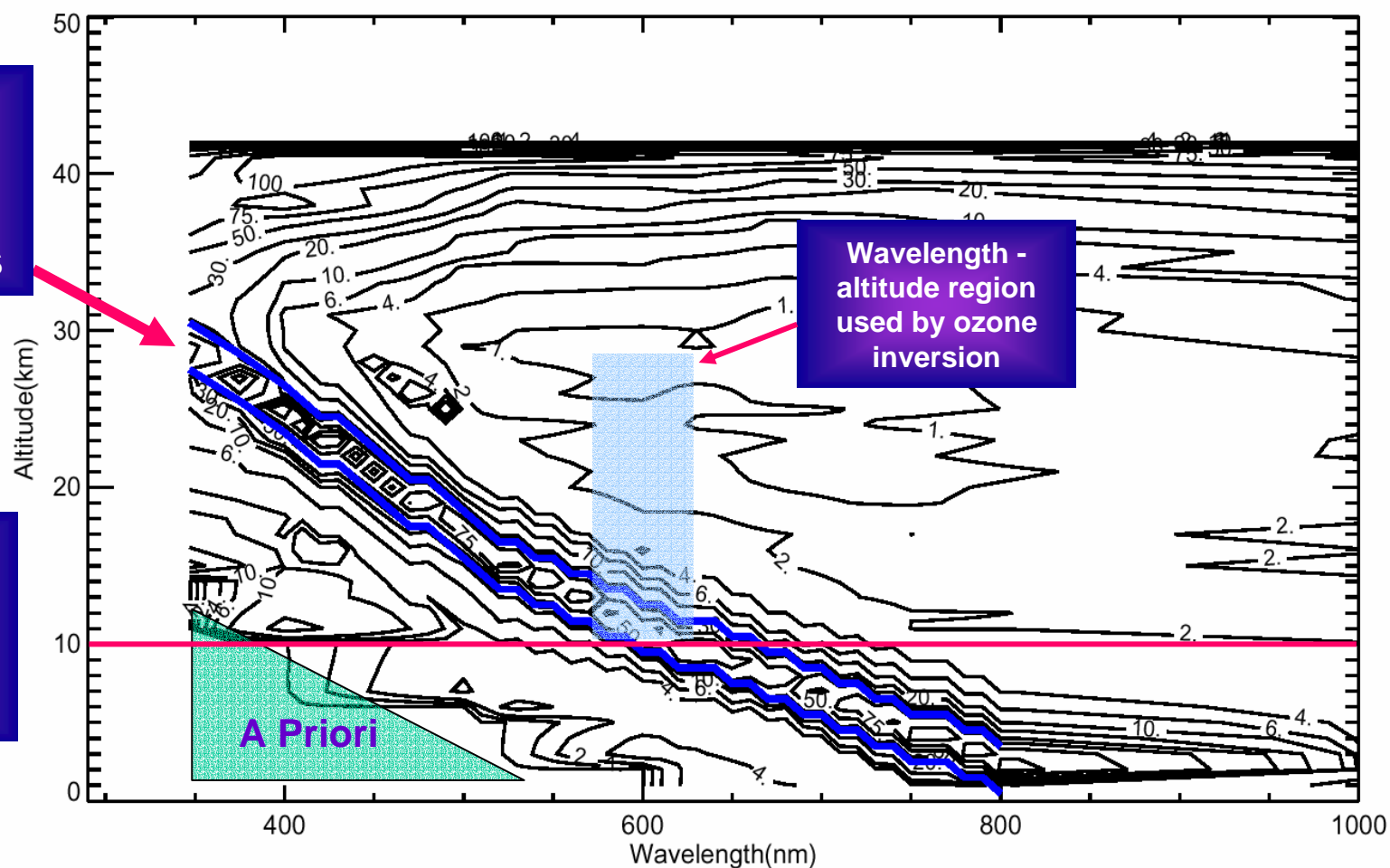
Aerosol Inversion Precision Errors

Background (pre-Pinatubo)



Limb
radiance
insensitive
to aerosols

Mid-latitude,
SZA=40,
AZ=0

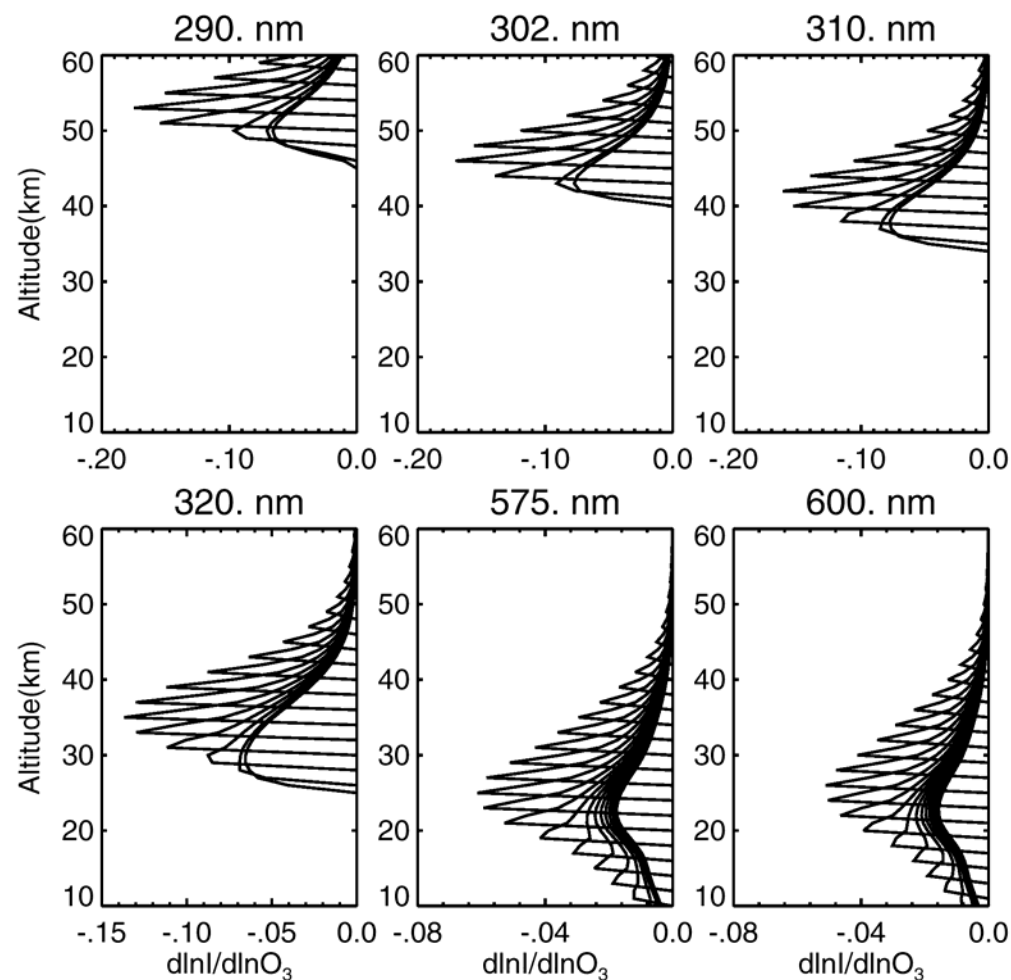


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Ozone Kernels Provide Vertical coverage from the Tropopause to 60 km



- UV channel pairs ratioed to 347 nm
- VIS channel triplets
- M325 atmosphere
- SZA=40, AZ=0
- 293, 296, 299 nm channels pairs and 616, 632 nm triplets not shown

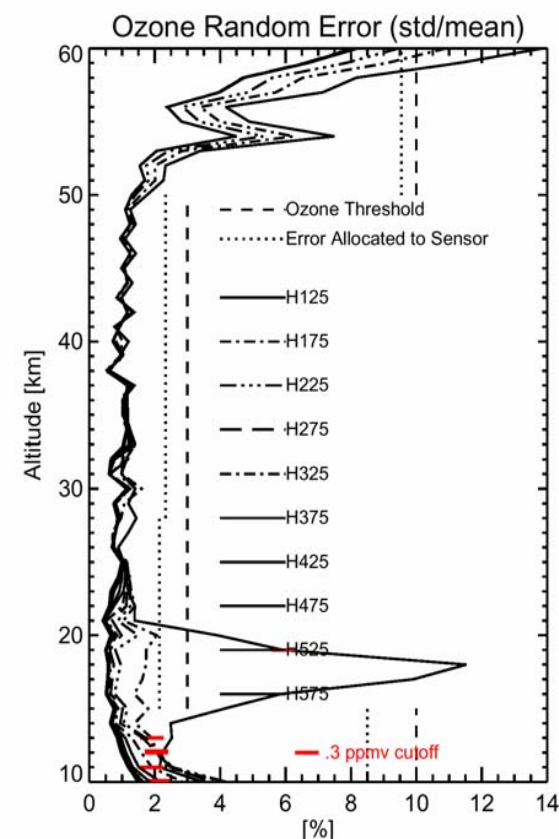
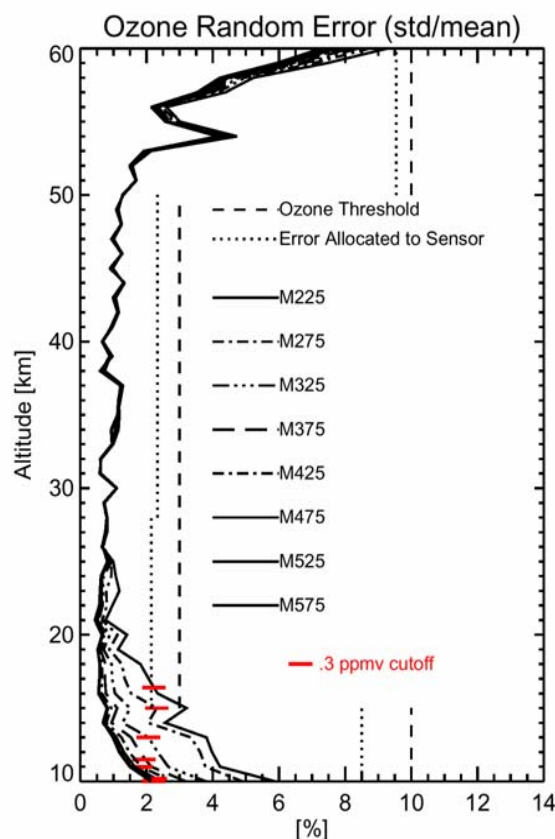
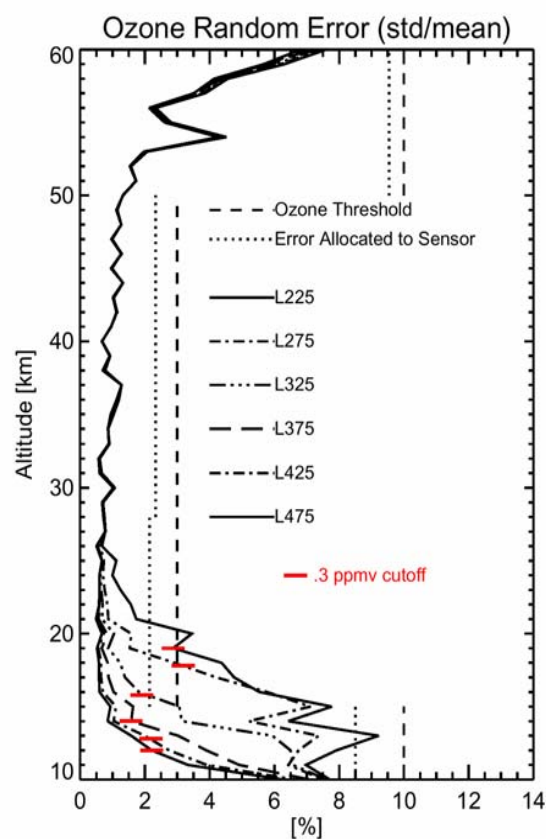


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Ozone Sensor Precision Errors Meet Allocations for Most Model Atmospheres



- TOMS V7 Standard profiles
- Background volcanic aerosol (May 9, 1991 30.1N)



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OMPS Limb Profiler Summary



- For operational monitoring of ozone, OMPS limb profiler performance will exceed SBUV/2
 - Vertical resolution
 - Vertical coverage
- Unique sensor design accommodates wide dynamic range of scene radiances and is spectrally optimized to match ozone absorption features
 - Sensor SNRs tailored to algorithm/EDR requirements
- Algorithm performance verified with on-going sensitivity studies
 - Limb scatter kernels sensitive to ozone, density, and aerosol
- OMPS algorithms to be tested on limb scatter observations
 - SAGE III and SOLSE/LORE II
- Engineering unit being built and tested fall-winter 2002-2003
- First flight currently planned for June 2011
 - Early flight of opportunity being pursued by NRL (OMPS-AE)